

METHOD AND SEALANT FOR WELD JOINTS

BACKGROUND OF THE INVENTION

1) Field of the Invention

The present invention relates to welding of structural members and, more particularly, relates to the sealing of weld joints, for example, to prevent corrosion at
5 the joints.

2) Description of Related Art

The joining of structural members often results in an interface that is susceptible to intrusion by chemicals, moisture, or other fluids and particulates. For example, in the aircraft industry, joints between structural members are often formed
10 by overlapping two or more structural members, forming holes through the members, and disposing rivets or other fasteners through the holes. Although the overlapping members may correspond closely to one another at their interface, each interface nevertheless typically defines a narrow space or crevice-like gap through which moisture, chemicals, debris, and other foreign materials can be received, possibly
15 resulting in increased corrosion of the structural members and the fasteners. Therefore, a sealant such as a caulk-like organic material can be disposed in each interface to seal the interface and prevent the entry of foreign materials therein. The sealant can be disposed before or after the joint is formed, though in some cases the sealant is preferably disposed before joining because the geometrical configuration of
20 the structural members may prevent access to one or both sides of the interface after joining. In some cases, the sealant may be squeezed from the interface during joining, leaving unfilled voids in the interface, which can be difficult to identify and fill, especially if one or both sides of the joint cannot be accessed after joining. Further, even if the sealant does fill the interface, the sealant can dry out and deteriorate or
25 otherwise work free from the joint over time.

Joints can alternatively be formed by welding the structural members. For example, a friction stir weld joint can be formed by overlapping the structural members, rotating a friction stir welding pin extending in a direction generally perpendicular to the interface of the members, and urging the pin through the

members along the interface. The pin generates sufficient friction with the structural members to plasticize a portion of the members, and the plasticized material is mixed by the pin. As the plasticized material cools, a friction stir weld joint is formed, characterized by a mixed portion having a refined grain structure, referred to as a nugget. The nugget is typically not as wide as the interface of the overlapping members, and the members therefore define spaces in the interface in which corrosion can occur, similar to the space proximate to the rivet joints described above. A sealant can be disposed in the spaces; however, if the sealant is disposed before welding, care should be taken to avoid introducing the sealant into the nugget of the joint as conventional sealants can negatively impact the strength and/or corrosion resistance of the joint. For example, masking tape can be placed on the area of the structural members where the nugget will be formed, the sealant can be disposed on the structural members, and the masking tape can then be removed to generally leave a clean area for forming the nugget. This process is time consuming. Further, even if such precautions are taken, as the members are placed and urged together to form the joint some of the sealant can be squeezed into the interface and mixed with the plasticized material of the joint, thereby reducing the quality of the weld joint. In addition, as described above, voids can result in the interface during joining or the sealant can be loosened from the interface subsequently.

Thus, there exists a need for an improved sealant and method for forming a corrosion resistant weld joint in a structural member. The sealant and method should be compatible with friction welding and should not be overly time consuming. Further, the sealant should form a strong bond to the structural member without excessively reducing the quality of the weld joint.

BRIEF SUMMARY OF THE INVENTION

The present invention provides a sealant and method for forming a weld joint between structural members. The sealant, which is disposed between faying surfaces of the structural members, includes aluminum and germanium and is characterized by a melting temperature that is lower than the melting temperature of the at least one structural member, and lower than the highest temperature generated during friction stir welding. The sealant can fill the spaces between the structural members to prevent the entry of chemicals, moisture, debris, and other substances, thereby reducing the likelihood of corrosion of the joint or structural members at the interface.

Further, the sealant can be diffusion bonded to the faying surfaces, for example, by the heat generated during the joining process, thereby substantially eliminating the risk that the sealant may work free over time.

According to one embodiment of the present invention, the weld joint is
5 formed between first and second faying surfaces of respective structural members in an opposed configuration to define an interface therebetween. The weld joint extends through the interface and connects the first and second faying surfaces. For example, the faying surfaces of the structural members can be substantially parallel, and the weld joint can be substantially perpendicular to the interface of the faying surfaces.
10 The joint can be formed by friction stir welding and can include a nugget area characterized by a refined granular structure. The sealant, which is disposed in and substantially fills the interface, is diffusion bonded to the faying surfaces. In addition to aluminum and germanium, the sealant can include strontium, silver, and silicon. Typically, the sealant includes between about 10% and 51.6% germanium by weight.
15 For example, the sealant can include about 51.6% germanium and about 48.4% aluminum by weight, or the sealant can alternatively include about 30.2% germanium, about 36.8% silver, and about 33% aluminum by weight. The sealant can be characterized by a melting temperature less than about 500 °C, for example, about 420 °C, and the sealant can be cathodic relative to the at least one structural member.
20 The present invention also provides a method of sealing a weld joint. The method includes providing at least one structural member and disposing a sealant on at least one of first and second faying surfaces of the structural member. For example, the sealant can be plasma sprayed onto one or both of the faying surfaces and can be disposed in a thickness such as between about 0.001 and 0.003 inches.
25 The sealant includes aluminum and germanium and is characterized by a melting temperature that is lower than the melting temperature of the at least one structural member, as described above. The faying surfaces are positioned in an opposing configuration to form an interface therebetween, and the structural member is welded to form a weld joint extending through the interface. The sealant is heated to melt
30 and/or bond with the at least one structural member proximate to the weld joint to substantially fill the interface. The weld joint can be formed by friction stir welding, e.g., by rotating a friction stir welding pin that extends from a shoulder and urging the pin through the interface. Further, the structural members can be positioned so that

the faying surfaces overlap to form the interface with a width about equal to the width of the shoulder.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

5 Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

 Figure 1 is a section view in elevation illustrating a friction stir welding tool configured to weld structural members according to one embodiment of the present
10 invention;

 Figure 2 is a section view in elevation illustrating a weld joint formed by a friction weld joint according to one embodiment of the present invention;

 Figure 3 is a section view in elevation of a weld joint formed according to one embodiment of the present invention;

15 Figure 4 is an enlarged section view illustrating a portion of the weld joint of Figure 3 as indicated by Figure 3; and

 Figure 5 is an enlarged section view illustrating another portion of the weld joint of Figure 3 as indicated by Figure 3.

20 DETAILED DESCRIPTION OF THE INVENTION

 The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the invention are shown. Indeed, this invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein;
25 rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

 Referring now to the figures and, in particular, Figure 1, there is shown an apparatus for forming a weld joint 10 to connect first and second structural members 20, 22, as shown in Figure 2. Two structural members are typically joined by the
30 method of the present invention, but a single structural member can be joined, for example, a tubular member or otherwise curved member with adjoining edges. Alternatively, three or more structural members can be joined. In the illustrated configuration, the first structural member 20 is disposed so that a faying surface 24 of the first structural member 20 overlaps a faying surface 26 of the second structural

member 22 so that the two structural members 20, 22 form an interface 28 therebetween. A friction stir welding tool 30, including a rotatable pin 32 extending from a shoulder 34, is inserted through the interface 28 generally perpendicular to the interface 28. An anvil (not shown) or other support can be disposed against the second structural member 22 to oppose the friction stir weld tool 30. The friction stir welding tool 30 is then urged against the first structural member 20 and advanced along the interface 28 of the structural members 20, 22 as the pin 32 rotates. The motion of the pin 32 generates frictional heat, which plasticizes material from the structural members 20, 22, and the plasticized material is mixed by the pin 32. As the plasticized material cools and hardens, a friction stir weld joint 10 is formed connecting the two structural members 20, 22, as shown in Figure 2. The weld joint 10 is characterized by a nugget region 12 proximate to the path of the pin 32, the nugget region 12 being characterized by a refined granular structure.

The process of friction stir welding for joining structural members 20, 22 is known in the art and is described, for example, in U.S. Patent No. 5,460,317 to Thomas, et al., the entirety of which is incorporated herein by reference. The weld joint 10 formed by the configuration shown in Figure 1 is generally referred to as a lap joint, i.e., a joint generally perpendicular to the interface of overlapping members. In other embodiments of the present invention, other weld joints can alternatively be formed by friction stir welding. In addition, other types of friction welding, such as linear friction welding, can also be used to join members, as can welding devices and methods other than friction welding devices and methods. Further, the structural members 20, 22 can also be joined without welding, for example, by solder joints, braze joints, rivets, bolts, clips, other fasteners, crimps, and the like. The present invention is not limited to these or other types of joints, and instead can be used with a wide variety of joints for connecting structural members 20, 22.

The structural members 20, 22 can define any of a variety of shapes such as sheets, plates, blocks, and the like. The members 20, 22 can be formed of metals, such as aluminum, titanium, or alloys thereof. Further, the members 20, 22 can be joined to create an assembly used for various applications including frames, panels, skins, airfoils, and the like for aeronautical and aerospace structures, such as aircraft and spacecraft, marine vehicles, automobiles, and the like. In some applications, the members 20, 22 are joined in geometrical configurations that make difficult or prevent subsequent access for inspecting or treating the joint 10. For example, the

structural members **20, 22** can be overlapped and joined to form a partially or fully closed body such as an airplane wing.

Although the faying surfaces **24, 26** of the structural members **20, 22** can correspond closely in contour, the interface **28** is characterized by spaces or voids **14** between the surfaces **24, 26** where the weld joint **10** is not formed, i.e., on either side of the weld joint **10**. According to one embodiment of the present invention, a sealant **16** is disposed between the structural members **20, 22** at the interface **28** thereof. The sealant **16** can be disposed on one or both of the faying surfaces **24, 26** of the structural members **20, 22**, and can be disposed over part or all of the area of the interface **28**, including the nugget region **12**. Thus, the sealant **16** can fill the spaces **14** between the faying surfaces **24, 26** of the structural members **20, 22**. The sealant **16** prevents chemicals, moisture, debris, and other substances from entering the spaces **14**, and the sealant **16** thereby prevents corrosion or other damage that can be caused by those substances.

Preferably, the sealant **16** is characterized by a melting temperature that is less than the melting temperature of the structural members **20, 22** and the highest temperature generated during friction stir welding so that the sealant **16** can be bonded to portions of the faying surfaces **24, 26** of the structural members **20, 22**, including portions of the faying surfaces **24, 26** where the structural members **20, 22** are not melted during welding. The term “melting temperature,” is meant to refer to a temperature at which the sealant **16** becomes at least partially melted and sufficiently hot for diffusion bonding to the structural members **20, 22**. In some embodiments, the sealant **16** is formed of multiple constituent materials, one or more of which can have a melting temperature that is equal to or higher than the melting temperature of the sealant **16** and/or the structural members **20, 22**. Further, the melting temperature of the sealant **16** can be lower than the melting temperatures of all of the constituent materials. The melting temperature of the sealant **16** can be less than about 500 °C, for example, between about 350 °C and 450 °C, which is less than the melting temperature of many aluminum and titanium alloys and lower than the temperatures at which these materials are typically friction stir welded. Thus, the melting temperature can be sufficiently low so that some or all of the sealant **16** is melted during the weld process, for example, by the frictional heat generated during friction stir welding.

According to one embodiment of the present invention, the sealant **16** is a mixture that includes germanium and aluminum. Germanium can be provided in an

amount between about 10% and 51.6% by weight of the sealant 16. Some or all of the remaining content of the sealant 16 can be aluminum. For example, the sealant 16 can include 51.6 weight % germanium and a balance of aluminum, a mixture characterized by a melting temperature of about 420 °C, which is generally the lowest melting temperature for a mixture that includes only germanium and aluminum, sometimes referred to as the eutectic temperature. The sealant 16 can also include one or more additional materials such as silicon, silver, and strontium. For example, the sealant 16 can include 30.2 weight % germanium, 36.8 weight % silver, and a balance of aluminum, a mixture characterized by a melting temperature of about 418 °C, the eutectic temperature for a mixture that includes only germanium, silver, and aluminum. Alternatively, the sealant 16 can comprise germanium, aluminum, and silicon, which can be characterized by a melting temperature of between about 420 °C and 500 °C. For example, the sealant 16 can include 60.5 weight % aluminum, 35 weight % germanium, and 4.5 weight % silver, an alloy characterized by a melting temperature of about 500 °C. Further, the sealant 16 can include other constituents that enhance the material properties or reduce the cost of the sealant. For example, strontium, which can modify and refine the germanium, thereby increasing the ductility of the sealant 16, can be included in an amount less than about 0.5% by weight, such as between about 0.001% and 0.03% by weight.

The sealant 16 can also be electrochemically neutral or cathodic relative to the material of the structural members 20, 22 so that the sealant 16 is less susceptible to corrosion. For example, the aluminum-germanium mixtures described above are generally electrochemically neutral or cathodic to most aluminum and titanium alloys. According to one embodiment, if the sealant 16 is used with structural members 20, 22 formed largely of aluminum, the sealant 16 can contain little or no zinc, lithium, manganese, or magnesium, which are more anodic than aluminum.

The sealant 16 can be formed by any of various methods that are known in the art for forming powdered mixtures. For example, the sealant 16 can be formed by melting and mixing the constituent materials. The molten mixture can be cast and allowed to cool to form a solid ingot, which can then be ground into a fine powder. The sealant 16 is then disposed on one or both of the faying surfaces 24, 26 of the structural members 20, 22 by spreading the sealant 16 by hand or spraying a coating of the sealant 16, for example, by plasma spraying, flame spraying, high velocity oxy-fuel spraying, and the like. The particles of the sealant 16 can be heated and melted

during the deposition process, while the structural members **20, 22** remain unmelted. Alternatively, the particles can remain unmelted during deposition. The amount of sealant **16** disposed on the faying surfaces **24, 26** can vary, but in one embodiment of the invention, a layer of between about 0.001 and 0.003 inches is disposed. The
5 sealant **16** can be disposed over all or part of the faying surfaces **24, 26**, including the portion of the interface **28** that is welded to form the nugget area **12** of the joint **10**, although in some cases the sealant **16** may positively or negatively affect certain mechanical properties of the joint **10**.

The sealant **16** is then heated to a temperature sufficient to thermally bond the
10 sealant **16** to the faying surfaces **24, 26** of the structural members **20, 22**, e.g., the melting temperature of the sealant **16**. The thermal energy for heating the sealant **16** can be generated entirely by the welding process. For example, if the structural members **20, 22** are friction stir welded, the frictional heat resulting from the motion of the pin **32** and the shoulder **34** can heat the structural members **20, 22** and the
15 sealant **16**, thereby melting the sealant **16** so that the sealant **16** flows fluidly, adheres to the faying surfaces **24, 26**, and is diffusion bonded thereto. While the sealant **16** close to the path of the pin **32** can be heated primarily by the pin **32**, the sealant **16** that is further from the pin **32** may be heated to a greater extent by frictional heat generated between the shoulder **34** and the first structural member **20** as the shoulder
20 **34** rotates against the structural member **20**. Advantageously, the diameter of the shoulder **34** can be increased so that the shoulder **34** generates frictional heat over a greater area of the structural member **20**. For example, according to one embodiment of the present invention, the diameter of the shoulder **34** is about equal to the width of the interface **28** so that the shoulder **34** generates frictional heat over the width of the
25 interface **28**.

Other welding or other connection methods can also sufficiently heat the sealant **16** to create the bond between the sealant **16** and the faying surfaces **24, 26**. In addition, a heat source (not shown) other than the device used for connection can be provided. For example, a radiant heater, such as an electric or gas oven or other
30 heater can be used to heat the sealant **16**. Alternatively, the heat source can be a laser that is used to direct light onto the sealant **16** to heat the sealant **16**. The laser can be configured to direct the light on the structural members **20, 22** or in a direction generally parallel to a plane of the interface **28** and toward the edges of the interface **28** to heat the sealant **16** at the perimeter of the interface **28**.

In some embodiments of the present invention, some of all of the sealant 16 is not heated to the melting temperature and, therefore, does not melt during the friction welding process. However, when subjected to sufficient heat and pressure during welding, the sealant 16 can be diffusion bonded at a temperature less than the melting temperature of the sealant 16. Thus, the sealant 16 can bond to the faying surfaces 24, 26 of the structural members 20, 22 and seal the interface 28 therebetween.

Figures 3-6 illustrate a weld joint 10 in which the spaces 14 defined by the interface 28 of the structural members 20, 22 have been sealed with the sealant 16. The weld joint 10 shown in Figures 3-6 are representative of one embodiment of the present invention, and it is understood that the structure, type, and configuration of the structural members 20, 22, sealant, and joint 10 as illustrated are representative only and numerous other weld joints 10 can alternatively be formed according to the present invention. As shown, the structural members 20, 22 are sheets of 7075-T6, an alloy formed primarily of aluminum, zinc, magnesium, copper, and chromium. The sealant 16, formed of 51.6 weight % germanium and a balance of aluminum, was manually spread on the faying surface 26 of the structural member 22 in solid particulate form. The structural members 20, 22 were then configured as illustrated to form the interface 28 therebetween and held in place while joined. Friction stir welding was performed using a friction stir welding device similar to the tool 30 illustrated in Figure 1, by urging the shoulder 34 of the tool 30 against the first structural member 20 so that the pin 32 extended generally perpendicular to the interface 28 and therethrough and moving the rotating pin 32 linearly along the interface 28. Frictional heat from the welding process melted some of the sealant 16.

Figures 4 and 5 are enlarged views of the weld joint 10 at two particular locations as indicated in Figure 3. As shown in Figures 4-5, the sealant 16, which appears lighter in color than the material of the structural members 20, 22, is diffusion bonded to both of the structural members 20, 22. In particular, granular eutectic portions 17 are formed where the sealant 16 has been at least partially melted and bonded to the structural members 20, 22. Sintered portions 18 are formed where the sealant 16 has not been melted but has been subjected to sufficient heat and pressure to form a metallurgical bond with the material of the structural members 20, 22. Each joint 10 formed according to the present invention can include granular eutectic portions 17 and/or sintered portions 18.

Many modifications and other embodiments of the invention set forth herein will come to mind to one skilled in the art to which this invention pertains having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. For example, while Figures 3-5 illustrate joints **10** formed by applying the sealant **16** to one of the faying surfaces **26**, the sealant **16** can be applied to either or both of the faying surfaces **24**, **26** in other embodiments of the present invention. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.